Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Load (TMDL)

for

Spring Fork Lake
Pettis County, Missouri

Completed: June 29, 2006
Approved:

Total Maximum Daily Load (TMDL)
For Spring Fork Lake
Pollutant: Nutrients

Name: Spring Fork Lake

Location: Between Sedalia in Pettis County and Cole Camp in Benton County, Missouri

Hydrologic Unit Code (HUC): 10300103-010004

Water Body Identification (WBID): 7187

Missouri Lake Class: L1[1]

Beneficial Uses[2]:
- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health [associated with] Fish Consumption
- Secondary Contact Recreation
- Drinking Water Supply

Size of Impairment: 178 acres

Location of Impaired Lake: Wholly contained in Sections 21 and 28, T44N, R21W

Pollutant: Nutrients

Pollutant Source: Agricultural Nonpoint Source

TMDL Priority Ranking: Low

1. Background and Water Quality Problems

Area History:
Spring Fork Lake is in Pettis County, with a part of its watershed extending into Benton County. When the Osage Tribe lived in present day Pettis County, it was mostly open prairie. According to one history of Sedalia[3] (nine miles north of the lake), there was waist high grass, Carolina parrots, passenger pigeons and plenty of bass in Pearl River, now called Sewer Branch, which runs through Sedalia. About 700 people lived in Pettis County when it was formed from west Cooper County

[1]Class L1 lakes are lakes used primarily for public drinking water supply. See Missouri's Water Quality Standards 10 CSR 20-7.031(1)(F)
[2] The beneficial uses may be found at 10 CSR20-7.031 (1)(C) and Table G
[3] The First One Hundred Years, Hurlbut Printing Co. Inc., Sedalia, Mo., just prior to the 1960 census.

and the southern two-thirds of Saline County on Jan. 28, 1933. The county was named for Spencer Pettis, who was the third representative to Congress from Missouri and served from 1828 to 1831. Interestingly, Pettis was a protégé of Senator Thomas Hart Benton, after whom neighboring Benton County was named. The upper watershed for Spring Fork Lake lies in Benton County.

Sedalia was named for the youngest daughter of an early settler in Pettis County, George R. Smith. When Mr. Smith moved his large family from Kentucky to Missouri, he settled them in Georgetown, three miles north of present-day Sedalia, which became the county seat in 1837. He bought acreage on Muddy Creek in 1857, laid out the city of Sedalia and raised money to attract the Missouri Pacific Railroad to build across the high plain past Sedalia instead of along the Missouri River. He named the town Sedville for his daughter, Sarah E. Smith, whose pet name was "Sed". At the suggestion of a friend, he later changed the name to Sedalia.

Soils and Land Use:

The soils in the Spring Fork Lake watershed are in the Maplewood-Paintbrush-Eldon association. These soils exhibit slow to moderate permeability and moderate to rapid runoff, depending on slope. They are formed in loess and cherty limestone or dolomite residuum. Maplewood silt loam has a two to five percent slope while Paintbrush silt loam and Eldon gravelly silt loam have slopes of five to nine and three to nine percents respectively. The bottomland soils along the streams are the nearly level Dockery and Otter silt loams with moderate permeability and slow runoff. The rock that underlies these soils is shale and limestone.

Land use in the lake's watershed is two percent water (141 acres), 12 percent woodland (864 acres), 22 percent cropland (1521 acres) and 64 percent grassland (4489 acres). Livestock in the watershed include 200 hogs, 800 head of cattle and 88,000 poultry[4]. See also the land use map in Appendix A (acreage numbers are slightly different since a different source was used to create the map).

Defining the Problem:

Spring Fork Lake lies approximately nine miles south of Sedalia down Route 65, just south of Route V and west of Route U. The upper watershed is near Cole Camp, which is in Benton County. The lake was formed in 1926 by impounding Cheese Creek, which is a tributary to Spring Fork Creek. Spring Fork, in turn, runs into Flat Creek, which joins with Richland Creek to form the Lamine River. The dam is 43 feet high.

The lake serves as a drinking water source for the City of Sedalia. There have been occasional complaints about taste and odor problems in the city's drinking water supply, which triggered the listing of the lake on the 303(d) list in 1998. Taste and odor problems are usually related to the presence of large amounts of algae (often the die-off of a large amount of algae) in a drinking water supply source. Large algal populations are stimulated by excess amounts of nitrogen and phosphorus (nutrients). The watershed of Spring Fork Lake is agricultural in nature, with commercial fertilizer and animal manure use as sources of nitrogen and phosphorus. A local watershed group has been organized to write a Source Water Protection Plan to protect the lake, their drinking water reservoir. This volunteer group will investigate all possible ways to accomplish its objective. The problems they have identified in the watershed include cattle watering in Cheese Creek and its tributaries, overuse of fertilizer, animal feeding operations and pollutants transported

[4] Information provided by Jerry Morhain, Sedalia Water Department, 6/9/05.

by runoff. Implementation of nutrient management plans on farms in this watershed may be an effective means of reducing the present problem. Also, since there was historically only one sampling site on the lake and very little data, members of the watershed group requested training to do stream and lake monitoring. The Volunteer Water Quality Monitoring activity under the Missouri Stream Team program and the Missouri Lakes Volunteer Program provided this training to the watershed group. The first year volunteers collected data was 2004.

The lake is also used for boating and fishing. The fish caught are small and largemouth bass, bluegill, catfish and crappie.

2. Description of the Applicable Water Quality Standards and Numeric Water Quality Targets

Beneficial Uses:
The beneficial uses of Spring Fork Lake, WBID 7187, are:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health [associated with] Fish Consumption
- Secondary Contact Recreation
- Drinking Water Supply

The uses that are impaired:

- Drinking Water Supply

Anti-degradation Policy:
Missouri's Water Quality Standards include the Environmental Protection Agency (EPA) "three-tiered" approach to anti-degradation, which may be found at 10 CSR 20-7.031(2).

Tier 1 – Protects existing uses and provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after November 29, 1975, the date of EPA's first Water Quality Standards Regulation, or uses for which existing water quality is suitable unless prevented by physical problems such as substrate or flow.

Tier 2 – Protects the level of water quality necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water in waters that are currently of higher quality than required to support these uses. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economical or social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national resources, such as waters of national and state parks, wildlife refuges and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality (with the exception of some limited activities that result in temporary and short-term changes in water quality).

Specific Criteria:
The impairment of Spring Fork Lake is based on exceedence of the general criteria contained in Missouri's Water Quality Standards, 10 CSR 20-7.031 (3)(A) and (C). These criteria state:

- Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly or harmful bottom deposits or prevent full maintenance of beneficial uses.
- Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor or prevent full maintenance of beneficial uses.

The impairment is also based on influencing the specific criteria at 10 CSR 20-7.031(4)(F) on Taste- and Odor-Producing Substances. There it says (in part):

> For those streams and lakes designated for drinking water supply use, the taste- and odor-producing substances shall be limited to concentrations that will not interfere with the production of potable water by reasonable water treatment processes.

Numeric Water Quality Target:
Excessive nutrients are causing the lake to be impaired, yet Missouri presently has no specific criteria for nutrients (phosphorus and nitrogen). Therefore, some number or level of nutrients must be derived that can be tied to the narrative criteria and can be used as the endpoint or target for Spring Fork Lake (see Reference Lake Approach below). When nutrient criteria become available, the TMDL may be adjusted to reflect them.

Chlorophyll-a occurs in all green plants and is used as a measure of the amount of algae. When certain types of algae, blue-green algae, die, they release particular compounds that cause unpleasant taste and odor. It has been found that suspended chlorophyll-a predicts the risk of dominance of blue-green algae. This risk increases exponentially when chlorophyll-a exceeds 10 µg/L[5] (MDNR, 2004). While Missouri does not have specific standards for nutrients, 25µg/L total phosphorus (TP) has been suggested for the nutrient phosphorus standard for lakes (USEPA 2000). In addition, 27 µg/L TP was used for the McDaniel Lake TMDL as the concentration of phosphorus that would limit chlorophyll-a to 10 µg/L (MDNR, 2005). Appendices C-1 to C-3 summarize Chlorophyll-a and TP data for Spring Fork Lake. Appendix B contains a map of the lake showing the location of the sampling point. Appendix D shows the linear regression between Chlorophyll-a and TP for summer months (July – September). For comparison purpose, a scatter plot is presented using Chlorophyll-a and TP data for all months, also in Appendix D.

Reference Lake Approach[6]

The reference lake approach was used to derive the nutrient target for this TMDL. The "Reference Lake Approach" compares two lakes, one attaining its uses and one impaired based on biological assessments. The objective of the process is to reduce the ambient concentration of pollutants in the impaired lake to a level equivalent to the one in the non-impaired, reference lake. The

---

[5] µg/L = micrograms per liter. This is the same as parts per billion.
[6] This reference lake approach, the calculations in sections 2 – 7, and the graphs in Appendix D were produced by Parsons Corporation, a Pasadena-based engineering and construction firm.

corresponding load reduction will result in conditions favorable to the return of a healthy biological community to the impaired lake.

In general, three factors are considered when selecting a suitable reference lake. The first factor is to use a lake that has been assessed and determined to be meeting water quality standards. The second factor is that the reference lake should be about 20 to 30 percent of the size of the watershed and the volume of the impaired lake. The third and last factor is to find a lake with a watershed that closely resembles that of the impaired lake in hydrologic properties such as land use/cover, physiographic characteristics, and geology (USEPA, 1998). Tables 1 and 2 illustrate the hydrologic characteristics and land use distributions of three candidate reference lakes, relative to Spring Fork Lake. Data on these lakes are synthesized from research study of "Developing nutrient criteria for Missouri lakes" by Knowlton and Jones (2003).

Table 1: Characteristics of Candidate Reference Lakes

Name	Latitude	Longtitude	Volume (ac-ft)	Area (ac)	Depth (m)	Distance from Impaired Lake (mi)
Spring Fork	38.568333	-93.241389	1613	92.7	8.54	n/a
Pape (Concordia)	38.934720	-93.581500	1868	286.9	2.59	31.6
Blind Pony	39.031600	-93.368050	1812	107.2	4.57	32.7
Westmoreland	38.607222	-93.288611	657	65.6		3.7

Note: ac-ft = acre-feet; ac = acre; m = meters; mi = miles

The Edwin A. Pape Lake is in southeast Lafayette County, Blind Pony Lake is in southwest Saline County and Westmoreland Lake is in south central Pettis County. Both E. A. Pape and Blind Pony lakes are in Conservation Areas.

Table 2: Land Use Distribution of Candidate Reference Lakes

Lake Name		Land Use (acre)						Land Use Distribution (%)					
	Wateshed (ac)	Crops	Grassland	Wooded	Water	Urban	Barren	Crops	Grassland	Wooded	Water	Urban	Barren
Spring Fork	**7023**	**1521**	**4489**	**864**	**141**	**0**	**8**	22%	64%	12%	2.0%	0.0%	0.11%
Pape (Concordia)	5423	2571	1549	786	351	166	0	47%	29%	14%	6.5%	3.1%	0.00%
Blind Pony	3254	1170	967	871	205	41	0	36%	30%	27%	6.3%	1.3%	0.00%
Westmoreland	3621	787	1954	576	107	197	0	22%	54%	16%	3.0%	5.4%	0.00%

Based on land use, hydrologic and water quality data for these candidate reference lakes nearby (Tables 1 and 2), the closet matches for all above criteria for the Spring Fork Lake is the Edwin A. Pape Lake.
Table 3 shows the regression analysis results using available data in summer months (July – September) from the selected reference lake (E. A. Pape Lake). Based on these results, the TMDL endpoint is established as 36 µg/L TP (corresponding to 16 µg/L chlorophyll-a) in this TMDL study.

Table 3: Established TP Target using Selected Reference Lake

Impaired Lake	Reference Lake	Chl-a (ug/L): 75% of reference lake data	Chl-a (ug/L): 25% of impaired and reference lake data	y	R2	P	a	b	x	TP target (ug/L)
Spring Fork	Pape*	34.95	16.03	1.2049	0.6676	0.00	0.8763	-0.154	1.5511	35.57

log value equation: y =ax + b
x = log (targetted TP value)
y = log (lesser of Chl-a using 75% of reference lake data or 25% of all lake data)

* Several outliers were removed from these data sets to produce workable regressions.

3. Load Capacity

Load Capacity (LC) is defined as the greatest amount of a pollutant (the load) a waterbody can assimilate without violating Missouri Water Quality Standards. This total load is then divided among a Wasteload Allocation (WLA) for point sources, a Load Allocation (LA) for nonpoint sources and a Margin of Safety (MOS) to account for uncertainties. As an equation, looks like this:

$$\mathbf{LC = WLA + LA + MOS} \qquad \text{(Eq. 1)}$$

To calculate the LC, the following steps were used:

(1) Estimate the mean residence time of the lake (Appendix E provides the details of the calculation steps)
Result: 0.189 year, following methodology by Jones et. al (2004)
(2) Calculate the mean annual flow based on estimated residence time
Result: 8,534 acre feet per year (ac-ft/yr)
(3) Use the equation below with target TP concentration of 36 µg/L (from Table 3) and the above estimated flow:

*Load Capacity (as pounds per year) = Target TP Concentration (in µg/L) * Flow (in ac-ft / yr) * 0.00272 (Conversion Factor)* (Eq. 2)

LC = 36*8,534 * 0.00272 = 836 lb/yr

Therefore, the LC for TP in Spring Fork Lake is 836 lb/yr.

4. Critical Conditions and Seasonal Variation

(1) Critical Condition for Low Flow/Dry Weather
The Clean Water Act [40 CFR 130.7(c)(1)] and USEPA'S TMDL regulations require that in developing TMDLs, one must "*take into account the critical conditions for stream flow, loading, and water quality parameters*". The "critical condition" is generally defined as the condition when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or

characteristic water uses. The intent of this requirement is to ensure that the water quality of the receiving water body is protected during times when it is most vulnerable.

The critical condition for this TMDL study is during summer low flow condition when the lake's volume is at its lowest and taste and odor events are most likely to occur. During the critical low flow period, impacts from wet weather sources are limited since storm runoff is minimal under dry weather conditions. Therefore, only data from the summer months (July through September) are used in the TMDL development.

(2) Considerations of Seasonal Variations
The TMDL target was derived using July through September data when taste and odor events in Spring Fork Lake were most likely to occur. By using data from this most problematic period instead of the entire year, the target is meant to prevent taste and odor occurrences year-round (MDNR, 2004). If a phosphorus limit were instituted for the growing season only, it would ignore the effects of nutrient re-suspension in the water column within the lake. For this reason, it is recommended that 40 µg/L TP and the corresponding 19 µg/L chlorophyll-a target shall be in effect year-round.

5. Margin of Safety

A Margin of Safety (MOS) is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The MOS is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the MOS can be achieved through one of two approaches:

(1) Explicit - Reserve a numeric portion of the loading capacity as a separate term in the TMDL.
(2) Implicit - Incorporate the MOS as part of the critical conditions for the waste load allocation and the load allocation calculations by making conservative assumptions in the analysis.

Based on data availability for this TMDL study and guidance from EPA and MDNR, an explicit margin of safety of 10 percent of the loading capacity is reserved for the MOS.

6. Waste Load Allocation (Point Source Loads)

The Wasteload Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. There are no point sources or Confined Animal Feeding Operations in the Spring Fork Lake's watershed. Therefore, the WLA for this TMDL is set as zero pounds per day.

7. Load Allocation (Nonpoint Source Load)

Load Allocation (LA) is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources. The LA can be calculated from (Eq. 1) by subtracting the WLA and MOS from the Load Capacity.

$$LC = WLA + LA + MOS \qquad \text{(Eq. 1)}$$

Rearranging the equation:

$$LA = LC - MOS - WLA \qquad \text{(Eq. 3)}$$

$$LA = 836 - 10\%*836 - 0 = 752 \text{ lb/yr}$$

Percentage of reduction required to meet calculated load capacity:
There is one sampling site used in monitoring the nutrient levels in Spring Fork Lake. Appendix C provides a summary of TP data during summer months. Average TP concentration for Spring Fork Lake during summer months (July – September) is 163 μg/L.

Summary results of estimating required percentage of reduction is given as follow:

(1) *Current TP Loading (lb/yr) = Current TP Concentration (in μg/L) * Flow (in ac-ft / yr) * 0.00272 (Conversion Factor)* (Eq. 4)

Current Loading (lb/yr) = 163 * 8,534 * 0.00272

Current Loading = 3,785 lb/yr

(2) Determination of Required Load Reduction

% TP Reduction = (Existing Load – LA) / Existing Loading (Eq. 5)
= (3,785 – 752) / 3,785 = 80%

Table 4 shows the distribution of the existing pollutant load by land use. Table 5 summarizes the nutrient TMDL results for Spring Fork Lake.

Table 4: Distribution of Existing Pollutant Load by Land Use

Land Use	Crops	Grassland/Shrubs	Wooded/Forest	Urban	Water	Barren	Total
Land Use (Acre)	1521	4489	864	0	141	8	7023
TP Loading Coefficient (lb/ac/yr)*	2.2	0.08	0.18	1.4	0	0	
TP Load (lb/yr)	3270	359	156	0	0	0	3785

*References:
(1) USEPA (1980). Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients, EPA Report 440-5-80-011;
(2) U.S. Army Corps of Engineers (2004). Review of Published Export Coefficient and Event Mean Concentration (EMC) Data, Report ERDC TN-WRAP-04-3;
(3) Alexander, R. B., Smith, R. A., and Schwarz, G. E. (2004). Estimates of Diffuse Phosphorus Sources in Surface Wastes of the United States using a spatially referenced watershed model, *Water Sciences and Technology*, 49(3): 1-10; and
(4) Haggard, B. E., Moore, P.A., Jr, Chaubey, I., Stanley, E. H. (2003). Nitrogen and Phosphorus Concentrations and Export from an Ozark Plateau Catchment in the United States, *Biosystems Engineering*, 86(1): 75-85

Table 5: Summary of Nutrient Results for Spring Fork Lake TMDL

TMDL (lb/day)	**23**
LC (lb/yr)	**836**
WLA (lb/yr)	**0**
LA (lb/yr)	**752**
MOS (lb/yr)	**84**
Existing Load (lb/yr)	**3,785**
% of Reduction	**80%**

8. Monitoring Plans for TMDL under the Phased Approach

Future monitoring of this lake involves both volunteers and department staff. A total of 20 volunteers have attended training and completed the Introductory Level VWQM for Stream Teams. Two teams are monitoring Cheese Creek and one team is monitoring Spring Fork Creek. In 2004, the Lakes of Missouri Volunteer Program (LMVP) started monitoring Spring Fork Lake. This program trains volunteers to collect high quality data from Missouri's lakes to monitor problems like excess nutrients. Volunteers collect data eight times a year from May through September. The parameters collected include Secchi depth, TP, total nitrogen, chlorophyll (total) and inorganic suspended solids. As part of the LMVP, the Sedalia Water Department collected data from Spring Fork Lake every 21 days from April to November in 2004 and will continue to do this. In addition, the department will schedule post-implementation monitoring beginning three years after implementation has been completed.

9. Implementation Plans

In 2003, the department started working with Sedalia Public Works on creating a Source Water Protection Plan for Spring Fork Lake. The Sedalia Source Water Protection Committee was formed January 2004 with seven members and support from both the department and EPA. Since the TMDL was scheduled for development at the same time, the committee could address both documents at once. The group meets regularly on the first Wednesday of each month and is working to create a comprehensive Watershed Management Plan for the Spring Fork Lake watershed. This group is very dedicated and active. They take the initiative and provide leadership and energy to get the community involved in various projects to improve the quality of water entering Spring Fork Lake. They met with Sedalia's mayor and City Council about impaired water. They have had public meetings with the Kiwanis Club, Noonday Optimist, Rotary club, Lion Club and the Sunrise Optimists. Four committee members took a watershed class in April 2004 and two have trained through Level I VWQM with the Stream Team Program. They also inspired the local Boy Scout troops to start activities at the lake, including trash clean-up and one Eagle Scout project. Their initiative, energy and accomplishments have not gone unnoticed. EPA requested Sedalia to be a co-presenter at the Community Involvement Conference and training in Buffalo, NY, in July 12-14, 2005. Also, the committee contributed background information to help with the TMDL development.

With the help of the federal Natural Resources Conservation Service (NRCS), the committee is working with farmers to install Best Management Practices (BMPs) on their farmland. Some of the BMPs being used are livestock exclusion, stream bank revetment, riparian buffer restoration and alternative watering.

This is a phased TMDL and if future data indicate that phosphorus and nitrogen levels do not decline, this TMDL will be re-opened and re-evaluated. This TMDL will be incorporated into Missouri's Water Quality Management Plan.

10. Reasonable Assurance

In most cases, "Reasonable Assurance" in reference to TMDLs relates only to point sources. As a result, any assurances that nonpoint source contributors of nutrients will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint source pollution can be found in the "Implementation" section of this TMDL (Section 9).

11. Public Participation

The department has worked closely with the Sedalia Source Water Protection Committee since its inception in 2003. The committee received a 319 mini-grant in September 2004 for developing a watershed management plan and holding public meetings. They held a farmer-producer meeting in October 2004 to talk about the importance of safe drinking water. The department gave a presentation at that meeting about the TMDL (what one is and why it is required) and how community input and actions were needed for implementing it. NRCS followed this by speaking about the types of practices that would help reduce the amount of nutrients entering the lake.

This TMDL was on public notice from May 12 to June 11, 2006. Groups who received the public notice announcement include the Missouri Clean Water Commission, the Water Quality Coordinating Committee, Parsons Corporation, 37 Stream Team volunteers in the watershed, and the four legislators representing Pettis and Benton Counties. Also, the department posted the notice, the Spring Fork Lake Information Sheet and this document on its Web site, making them available to anyone with access to the Web. The department has placed a copy of the notice, comments received and its responses in the Spring Fork Lake file, as detailed below.

12. Appendices and List of Documents on File with the Department

Appendix A – Land Use Map for the Spring Fork Lake Watershed
Appendix B – Location Map of Impaired Water Body
Appendix C – Water Quality Data 1989-2005
Appendix D – Linear Regression graphs between Chlorophyll-a and Total Phosphorus
Appendix E – TMDL Calculation

An administrative record on the Spring Fork Lake TMDL has been assembled and is being kept on file with the Missouri Department of Natural Resources. It includes the following:

- Lamine River Basin Management Plan, 1992, Missouri Department of Conservation, Fisheries Division
- Spring Fork Lake Diagnostic/Feasibility Study, Phase I, Interim Report (1990) by Booker Associates, Inc., St. Louis, Missouri
- Lake Assessment and Data, Missouri Department of Natural Resources, 1981
- TMDL for Spring Fork Lake, Pettis County, Jan. 2006, Parsons Corporation
- Spring Fork Lake Source Water Protection Plan
- Lakes of Missouri Volunteer Program Report - 2004

References

Alexander, R. B., Smith, R. A., and Schwarz, G. E. (2004). Estimates of Diffuse Phosphorus Sources in Surface Wastes of the United States using a spatially referenced watershed model, *Water Sciences and Technology*, 49(3): 1-10

Booker Associates, Inc. (1994). Phase 1 Diagnostic / Feasibility Study – Spring Fork Lake (Interim Report).

Haggard, B. E., Moore, P.A., Jr, Chaubey, I., Stanley, E. H. (2003). Nitrogen and Phosphorus Concentrations and Export from an Ozark Plateau Catchment in the United States, *Biosystems Engineering*, 86(1): 75-85

Jones, J.R., Knowlton, M.F., Obrecht, D.V., and Cook, E.A. (2004) Importance of landscape variables and morphology on nutrients in Missouri reservoirs, *Can. J. Fish. Aquat. Sci.* 61: 1503-1512 (2004)

Knowlton, M. F, and Jones, J. R. (2003). Developing nutrient criteria for Missouri lakes, Report prepared by Department of Fisheries and Wildlife Sciences, University of Missouri, Columbia, MO

Missouri Department of Natural Resources (MDNR) (1986). Missouri Water Atlas, MDNR, Division of Geology and Land Survey, Rolla, MO

Missouri Department of Natural Resources (MDNR) (2002). State 303(d) List and 305(b) Report, http://www.dnr.mo.gov/wpscd/wpcp/waterquality/303d/

Missouri Department of Natural Resources (MDNR) (2004). TMDL for McDaniel Lake, Greene County, Missouri, http://www.epa.gov/waters/tmdldocs/mcdaniel_lake_greenecty_finaltmdl.pdf

Missouri Department of Natural Resources (MDNR) (2004a). Quality Assurance Project Plan for Low Flow Surveys (State Fiscal Year 2004)

U. S. Department of Agriculture (USDA) (2005). National Handbook of Conservation Practices (NHCP), http://www.nrcs.usda.gov/technical/standards/nhcp.html

USEPA (1980). Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients, EPA Report 440-5-80-011

USEPA (1998). Lake and Reservoir Bioassessment and Biocriteria, EPA Report 841-B-98-007

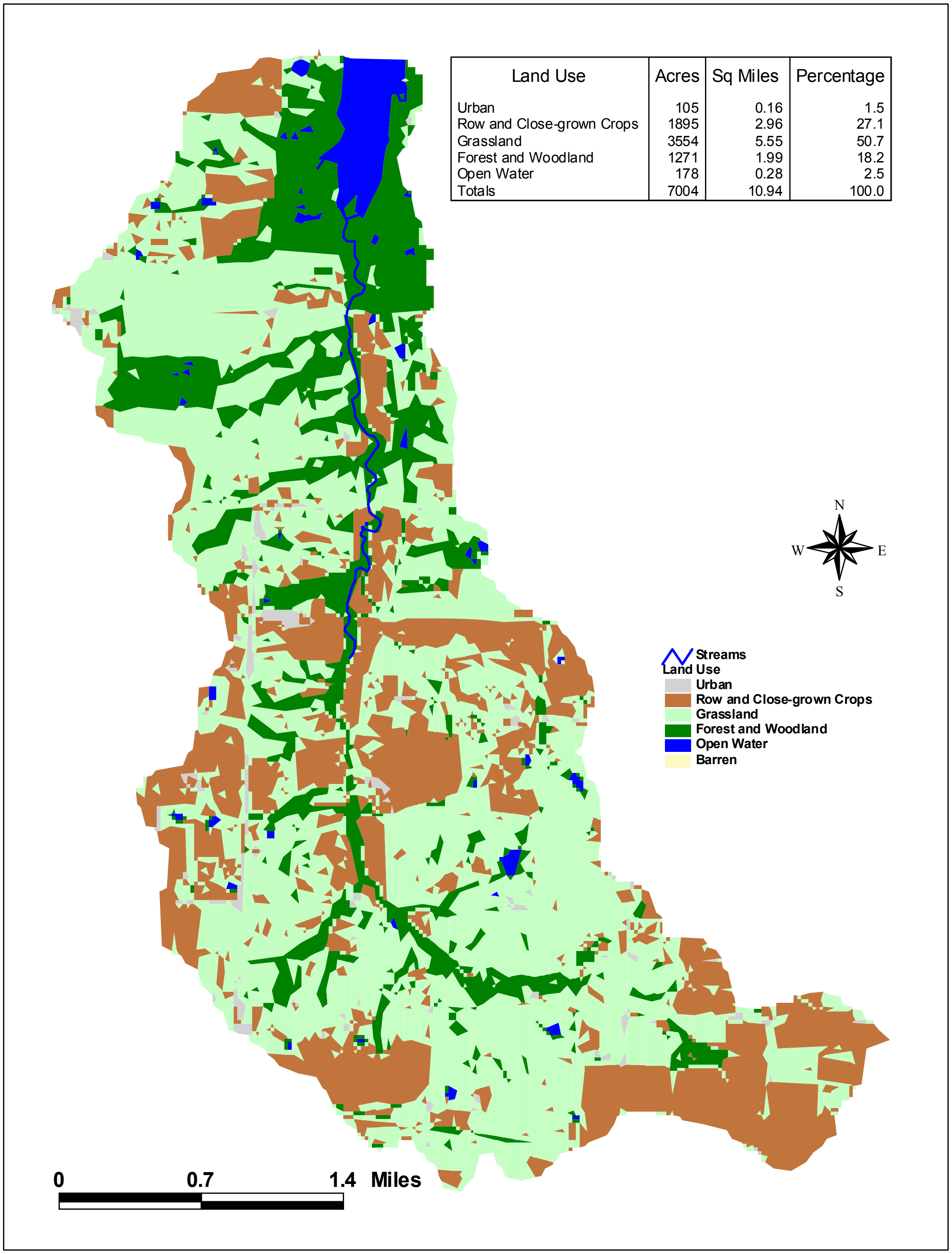
USEPA (1999). Protocol for Developing Nutrient TMDLs (First Edition), EPA Report 841-B-99-007

USEPA (1999a). Draft Guidance for Water Quality-based Decisions: The TMDL Process (Second Edition), EPA Report 841-D-99-001

USEPA (2000). Ambient Water Quality Criteria Recommendations: Lakes and Reservoirs in Nutrient Ecoregion XI, EPA Report 822-B-00-012

U.S. Army Corps of Engineers (2004). Review of Published Export Coefficient and Event Mean Concentration (EMC) Data, Report ERDC TN-WRAP-04-3

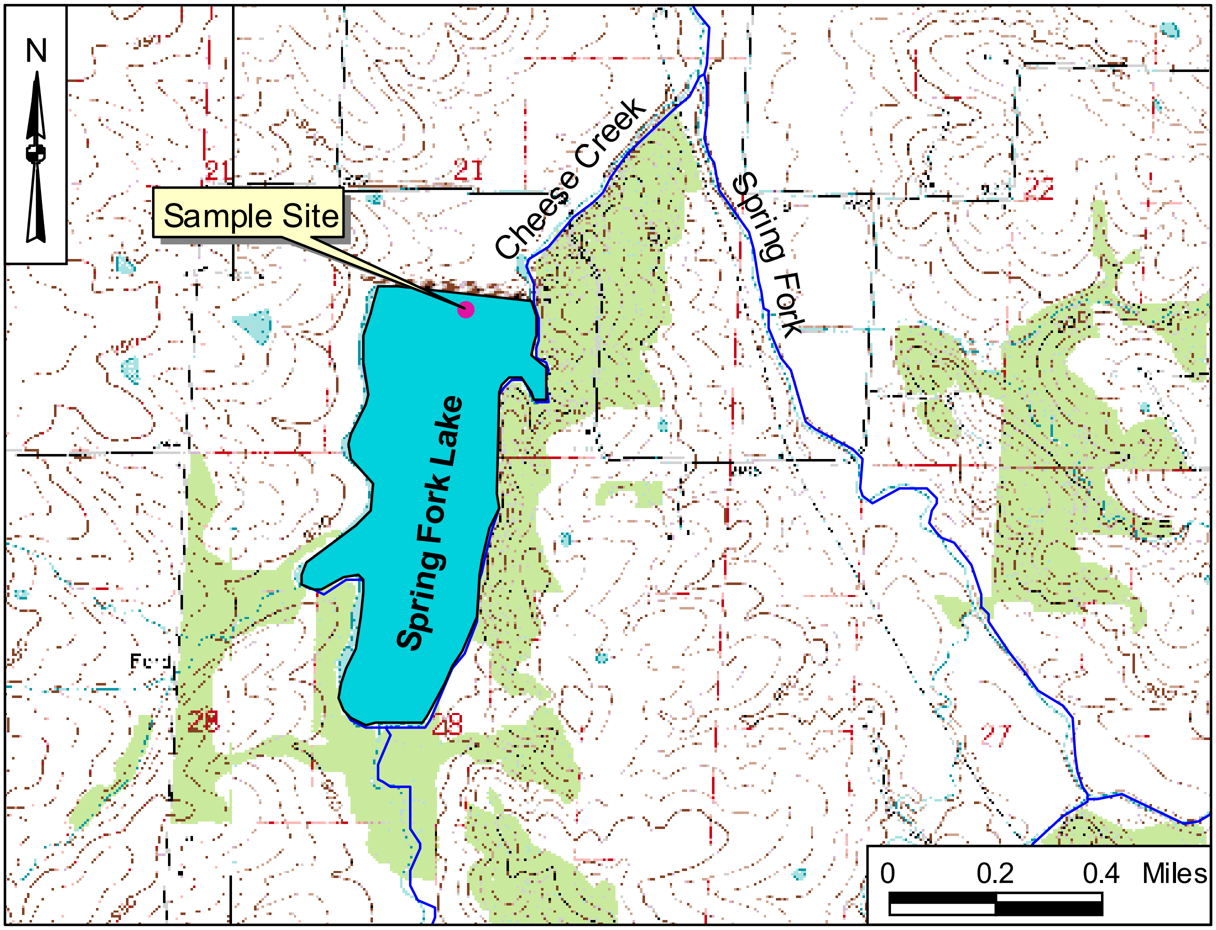
Appendix A
Land Use Map for the Spring Fork Lake Watershed



Land Use	Acres	Sq Miles	Percentage
Urban	105	0.16	1.5
Row and Close-grown Crops	1895	2.96	27.1
Grassland	3554	5.55	50.7
Forest and Woodland	1271	1.99	18.2
Open Water	178	0.28	2.5
Totals	7004	10.94	100.0

Data source: 2000 data (30 meter resolution) obtained from Thematic Mapper imagery was used to calculate land use statistics. These figures differ slightly from the land use figures (Knowlton and Jones, 2003) used in the TMDL calculations.

Appendix B
Spring Fork Lake in Pettis County, Missouri, with sampling sites



Appendix C
Water Quality Data for Spring Fork Lake

C-1. Water Quality Data (TP and Chl-a) for All Months
July 1988 – August 1998

Date	Sampling Site	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	log10 TP	log10 Chl-a
13-Jul-88	Near Dam	185.00	82.90	2.2672	1.9186
27-Jul-88	Near Dam	179.00	98.60	2.2529	1.9939
10-Aug-88	Near Dam	251.00	74.60	2.3997	1.8727
24-Aug-88	Near Dam	190.00	106.80	2.2788	2.0286
7-Sep-88	Near Dam	288.00	134.50	2.4594	2.1287
21-Sep-88	Near Dam	207.00	92.40	2.3160	1.9657
5-Jun-89	Near Dam	106.00	9.30	2.0253	0.9685
5-Jun-89	Near Dam	111.00	8.80	2.0453	0.9445
11-Jul-89	Near Dam	95.00	44.70	1.9777	1.6503
11-Jul-89	Near Dam	101.00	45.50	2.0043	1.6580
15-Aug-89	Near Dam	107.00	48.50	2.0294	1.6857
15-Aug-89	Near Dam	108.00	38.80	2.0334	1.5888
12-Jun-90	Near Dam	210.00	11.10	2.3222	1.0453
12-Jun-90	Near Dam	216.00	10.60	2.3345	1.0253
17-Jul-90	Near Dam	146.00	33.60	2.1644	1.5263
17-Jul-90	Near Dam	155.00	32.10	2.1903	1.5065
14-Aug-90	Near Dam	122.00	50.50	2.0864	1.7033
14-Aug-90	Near Dam	139.00	53.50	2.1430	1.7284
4-Jun-91	Near Dam	156.00	30.50	2.1931	1.4843
4-Jun-91	Near Dam	161.00	30.70	2.2068	1.4871
25-Jun-91	Near Dam	114.00	41.60	2.0569	1.6191
25-Jun-91	Near Dam	112.00	36.80	2.0492	1.5658
30-Jul-91	Near Dam	102.00	46.60	2.0086	1.6684
30-Jul-91	Near Dam	110.00	44.60	2.0414	1.6493
16-Jun-92	Near Dam	116.00	25.60	2.0645	1.4082
16-Jun-92	Near Dam	121.00	26.60	2.0828	1.4249
14-Jul-92	Near Dam	180.00	119.70	2.2553	2.0781
10-Aug-92	Near Dam	152.00	93.90	2.1818	1.9727
15-Jun-93	Near Dam	137.00	47.00	2.1367	1.6721
15-Jun-93	Near Dam	141.00	48.80	2.1492	1.6884
12-Jul-92	Near Dam	185.00	46.80	2.2672	1.6702
9-Aug-92	Near Dam	160.00	44.20	2.2041	1.6454
16-Mar-94	Near Dam	82.00	53.90	1.9138	1.7316
16-Mar-94	Near Dam	82.00	61.70	1.9138	1.7903
6-Apr-94	Near Dam	72.00	37.40	1.8573	1.5729
6-Apr-94	Near Dam	70.00	36.60	1.8451	1.5635
27-Apr-94	Near Dam	198.00	24.80	2.2967	1.3945
27-Apr-94	Near Dam	196.00	21.00	2.2923	1.3222
16-May-94	Near Dam	127.00	53.80	2.1038	1.7308
16-May-94	Near Dam	137.00	58.20	2.1367	1.7649

Date	Sampling Site	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	log10 TP	log10 Chl-a
13-Jun-94	Near Dam	106.00	53.00	2.0253	1.7243
13-Jun-94	Near Dam	121.00	56.20	2.0828	1.7497
11-Jul-94	Near Dam	103.00	49.00	2.0128	1.6902
11-Jul-94	Near Dam	103.00	49.70	2.0128	1.6964
10-Aug-94	Near Dam	131.00	58.70	2.1173	1.7686
10-Aug-94	Near Dam	128.00	60.00	2.1072	1.7782
31-Aug-94	Near Dam	140.00	66.70	2.1461	1.8241
31-Aug-94	Near Dam	140.00	60.20	2.1461	1.7796
21-Sep-94	Near Dam	178.00	109.70	2.2504	2.0402
21-Sep-94	Near Dam	168.00	114.20	2.2253	2.0577
12-Oct-94	Near Dam	151.00	122.20	2.1790	2.0871
12-Oct-94	Near Dam	153.00	103.70	2.1847	2.0158
2-Nov-94	Near Dam	134.00	107.20	2.1271	2.0302
2-Nov-94	Near Dam	132.00	109.70	2.1206	2.0402
7-Dec-94	Near Dam	197.00	12.40	2.2945	1.0934
7-Dec-94	Near Dam	197.00	12.80	2.2945	1.1072
30-May-95	Near Dam	193.00	10.00	2.2856	1.0000
30-May-95	Near Dam	197.00	9.00	2.2945	0.9542
26-Jun-95	Near Dam	134.00	15.30	2.1271	1.1847
26-Jun-95	Near Dam	129.00	16.40	2.1106	1.2148
31-Jul-95	Near Dam	112.00	29.00	2.0492	1.4624
31-Jul-95	Near Dam	112.00	28.20	2.0492	1.4502
3-Jun-98	Near Dam	135.00	30.20	2.1303	1.4800
3-Jun-98	Near Dam	125.00	31.20	2.0969	1.4942
1-Jul-98	Near Dam	244.00	39.60	2.3874	1.5977
1-Jul-98	Near Dam	244.00	39.90	2.3874	1.6010
1-Jul-98	Near Dam	260.00	39.60	2.4150	1.5977
22-Jul-98	Near Dam	170.00	52.60	2.2304	1.7210
22-Jul-98	Near Dam	172.00	49.60	2.2355	1.6955
22-Jul-98	Near Dam	176.00	50.10	2.2455	1.6998
12-Aug-98	Near Dam	182.00	49.60	2.2601	1.6955
12-Aug-98	Near Dam	175.00	49.60	2.2430	1.6955
12-Aug-98	Near Dam	198.00	58.60	2.2967	1.7679
Mean		151.60	51.39	2.1611	1.6252

C-2. Water Quality Data (TP and Chl-a) for Summer Months (July – September) July 1988 – August 1998

Date	Sampling Site	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	log10 TP	log10 Chl-a
13-Jul-88	Near Dam	185.00	82.90	2.2672	1.9186
27-Jul-88	Near Dam	179.00	98.60	2.2529	1.9939
10-Aug-88	Near Dam	251.00	74.60	2.3997	1.8727
24-Aug-88	Near Dam	190.00	106.80	2.2788	2.0286
7-Sep-88	Near Dam	288.00	134.50	2.4594	2.1287
21-Sep-88	Near Dam	207.00	92.40	2.3160	1.9657

Date	Sampling Site	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	log10 TP	log10 Chl-a
11-Jul-89	Near Dam	95.00	44.70	1.9777	1.6503
11-Jul-89	Near Dam	101.00	45.50	2.0043	1.6580
15-Aug-89	Near Dam	107.00	48.50	2.0294	1.6857
15-Aug-89	Near Dam	108.00	38.80	2.0334	1.5888
17-Jul-90	Near Dam	146.00	33.60	2.1644	1.5263
17-Jul-90	Near Dam	155.00	32.10	2.1903	1.5065
14-Aug-90	Near Dam	122.00	50.50	2.0864	1.7033
14-Aug-90	Near Dam	139.00	53.50	2.1430	1.7284
30-Jul-91	Near Dam	102.00	46.60	2.0086	1.6684
30-Jul-91	Near Dam	110.00	44.60	2.0414	1.6493
12-Jul-92	Near Dam	185.00	46.80	2.2672	1.6702
14-Jul-92	Near Dam	180.00	119.70	2.2553	2.0781
9-Aug-92	Near Dam	160.00	44.20	2.2041	1.6454
10-Aug-92	Near Dam	152.00	93.90	2.1818	1.9727
11-Jul-94	Near Dam	103.00	49.00	2.0128	1.6902
11-Jul-94	Near Dam	103.00	49.70	2.0128	1.6964
10-Aug-94	Near Dam	131.00	58.70	2.1173	1.7686
10-Aug-94	Near Dam	128.00	60.00	2.1072	1.7782
31-Aug-94	Near Dam	140.00	66.70	2.1461	1.8241
31-Aug-94	Near Dam	140.00	60.20	2.1461	1.7796
21-Sep-94	Near Dam	178.00	109.70	2.2504	2.0402
21-Sep-94	Near Dam	168.00	114.20	2.2253	2.0577
31-Jul-95	Near Dam	112.00	29.00	2.0492	1.4624
31-Jul-95	Near Dam	112.00	28.20	2.0492	1.4502
1-Jul-98	Near Dam	244.00	39.60	2.3874	1.5977
1-Jul-98	Near Dam	244.00	39.90	2.3874	1.6010
1-Jul-98	Near Dam	260.00	39.60	2.4150	1.5977
22-Jul-98	Near Dam	170.00	52.60	2.2304	1.7210
22-Jul-98	Near Dam	172.00	49.60	2.2355	1.6955
22-Jul-98	Near Dam	176.00	50.10	2.2455	1.6998
12-Aug-98	Near Dam	182.00	49.60	2.2601	1.6955
12-Aug-98	Near Dam	175.00	49.60	2.2430	1.6955
12-Aug-98	Near Dam	198.00	58.60	2.2967	1.7679
Mean		161.49	61.22	2.1892	1.7502

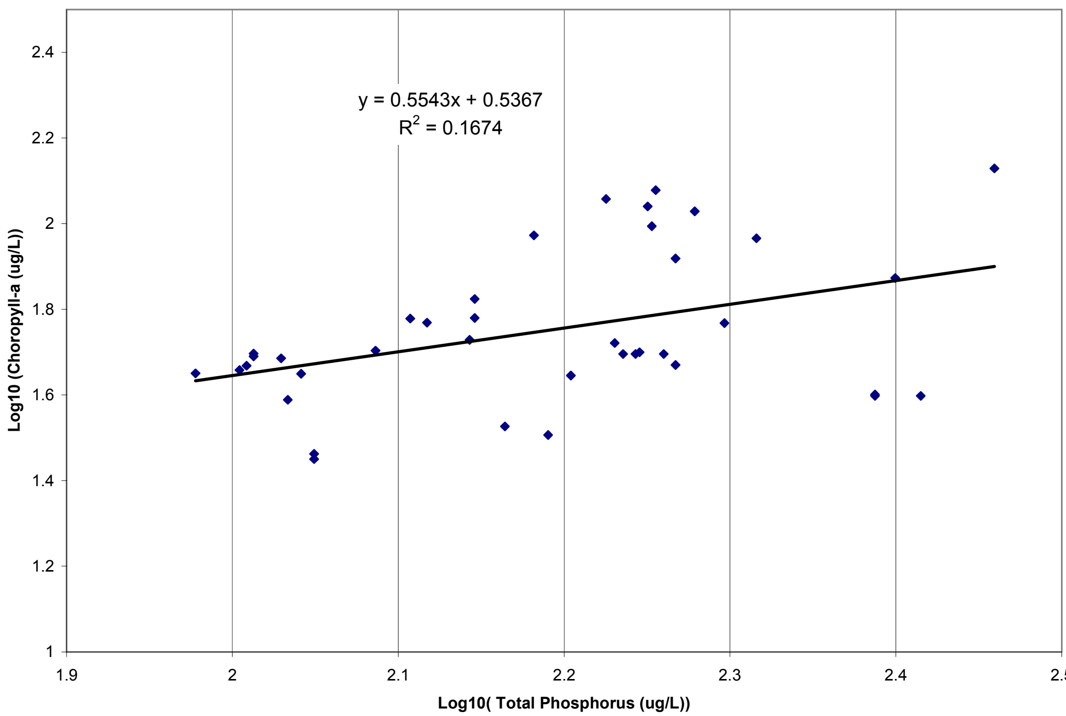
C-3. Total Phosphorus Data for Summer Months (July – September) July 1988 – September 2004

DATE	Sampling Site	Total Phosphorus (µg/L)	log10 TP
13-Jul-88	Near Dam	185.00	2.2672
27-Jul-88	Near Dam	179.00	2.2529
10-Aug-88	Near Dam	251.00	2.3997
24-Aug-88	Near Dam	190.00	2.2788
7-Sep-88	Near Dam	288.00	2.4594
21-Sep-88	Near Dam	207.00	2.3160

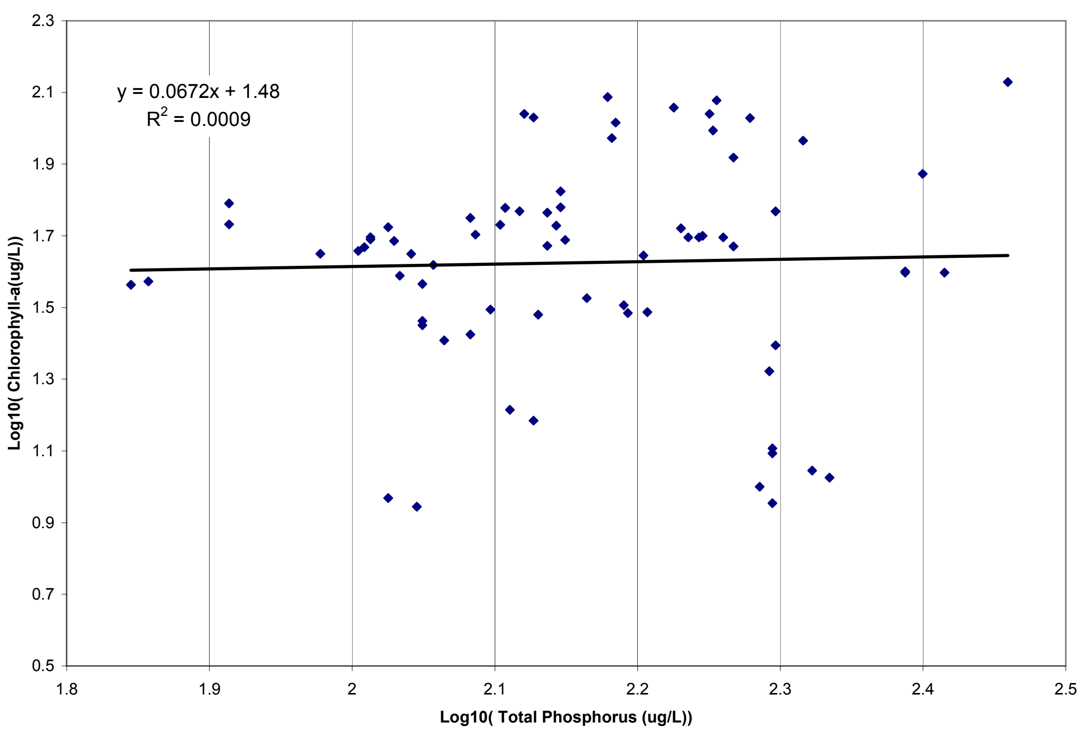
DATE	Sampling Site	Total Phosphorus (µg/L)	log10 TP
11-Jul-89	Near Dam	95.00	1.9777
11-Jul-89	Near Dam	101.00	2.0043
15-Aug-89	Near Dam	107.00	2.0294
15-Aug-89	Near Dam	108.00	2.0334
17-Jul-90	Near Dam	146.00	2.1644
17-Jul-90	Near Dam	155.00	2.1903
14-Aug-90	Near Dam	122.00	2.0864
14-Aug-90	Near Dam	139.00	2.1430
30-Jul-91	Near Dam	102.00	2.0086
30-Jul-91	Near Dam	110.00	2.0414
12-Jul-92	Near Dam	185.00	2.2672
14-Jul-92	Near Dam	180.00	2.2553
9-Aug-92	Near Dam	160.00	2.2041
10-Aug-92	Near Dam	152.00	2.1818
11-Jul-94	Near Dam	103.00	2.0128
11-Jul-94	Near Dam	103.00	2.0128
10-Aug-94	Near Dam	131.00	2.1173
10-Aug-94	Near Dam	128.00	2.1072
31-Aug-94	Near Dam	140.00	2.1461
31-Aug-94	Near Dam	140.00	2.1461
21-Sep-94	Near Dam	178.00	2.2504
21-Sep-94	Near Dam	168.00	2.2253
31-Jul-95	Near Dam	112.00	2.0492
31-Jul-95	Near Dam	112.00	2.0492
1-Jul-98	Near Dam	244.00	2.3874
1-Jul-98	Near Dam	244.00	2.3874
1-Jul-98	Near Dam	260.00	2.4150
22-Jul-98	Near Dam	170.00	2.2304
22-Jul-98	Near Dam	172.00	2.2355
22-Jul-98	Near Dam	176.00	2.2455
12-Aug-98	Near Dam	182.00	2.2601
12-Aug-98	Near Dam	175.00	2.2430
12-Aug-98	Near Dam	198.00	2.2967
1-Jul-04	Near Dam	174.00	2.2405
1-Jul-04	Near Dam	173.00	2.2380
22-Jul-04	Near Dam	170.00	2.2304
22-Jul-04	Near Dam	185.00	2.2672
12-Aug-04	Near Dam	153.00	2.1847
12-Aug-04	Near Dam	153.00	2.1847
2-Sep-04	Near Dam	286.00	2.4564
2-Sep-04	Near Dam	76.00	1.8808
22-Sep-04	Near Dam	170.00	2.2304
22-Sep-04	Near Dam	160.00	2.2041
MEAN		163.22	2.1938

Appendix D
Linear Regressions between Chlorophyll-a and TP in Spring Fork Lake

Regression for Summer Months (July – September)



Regression for All Data (1988-1998)



Appendix E
TMDL Calculation

The steps and values used in calculating the TMDL for Total Phosphorus are as follows:

(1) Average total phosphorus concentration for Spring Fork Lake during summer months (July – September) is 163 µg/L.

(2) Estimate mean residence time of the lake (Jones et. al, 2004):

Mean Residence Time = Lake Volume / Lake Inflow
Where,

Lake Volume = (1/4 Dam Height) * Lake Surface Area
Lake Inflow = Lake Watershed Area * Runoff (from Missouri Water Atlas)
Spring Fork Lake Surface Area = 92.7 acres; Lake Watershed Area = 7,023 acres

The residence time for Spring Fork Lake is estimated as 0.189 year (2.3 month). Please refer to the following table:

Residence Time Calculation	Dam Height (ft)	Lake Area (ac)	Volume (ac-ft)	Watershed (ac)	Runoff (inch)	Lake Inflow (ac-ft)	Residence Time (year)
Spring Fork Lake	43	92.7	997	7023	9	5267	0.189

References:
(a) Jones, J.R., Knowlton, M.F., Obrecht, D.V., and Cook, E.A. (2004) Importance of landscape variables and morphology on nutrients in Missouri reservoirs, *Can. J. Fish. Aquat. Sci.* 61: 1503-1512 (2004)
(b) Missouri Department of Natural Resources (MDNR) (1986). Missouri Water Atlas, MDNR, Division of Geology and Land Survey, Rolla, MO

(3) Calculate mean annual flow based on estimated residence time:
Estimated mean annual flow for Spring Fork Lake using the lake volume from Table 1 page 5
= 1613 ac-ft / 0.189 year = 8,534 ac-ft/yr

(4) Calculation of Target TP Loading:
Use equation below with target TP concentration of 36 µg/L (from Table 4) and the above estimated flow:
*Target TP Loading (lb/yr) = Target TP Concentration (in µg/L) * Flow (in ac-ft/yr) * 0.00272 (Conversion Factor)*

Target TP Loading (lb/yr) = 36 * 8,534 * 0.00272

Target TP Loading / Loading Capacity = 836 lb/yr

TMDL = 836 lb/yr divided by 365 days per year = 22.9 pounds per day (lb/day)

(5) Calculation of Current TP Loading:
Use equation below with current TP concentration of 163 µg/L and the above estimated flow:
*Current TP Loading (lb/yr) = Current TP Concentration (in µg/L) * Flow (in ac-ft/yr) * 0.00272 (Conversion Factor)*

Current TP Loading (lb/yr) = 163 * 8,534 * 0.00272

Current TP Loading = 3,784 lb/yr